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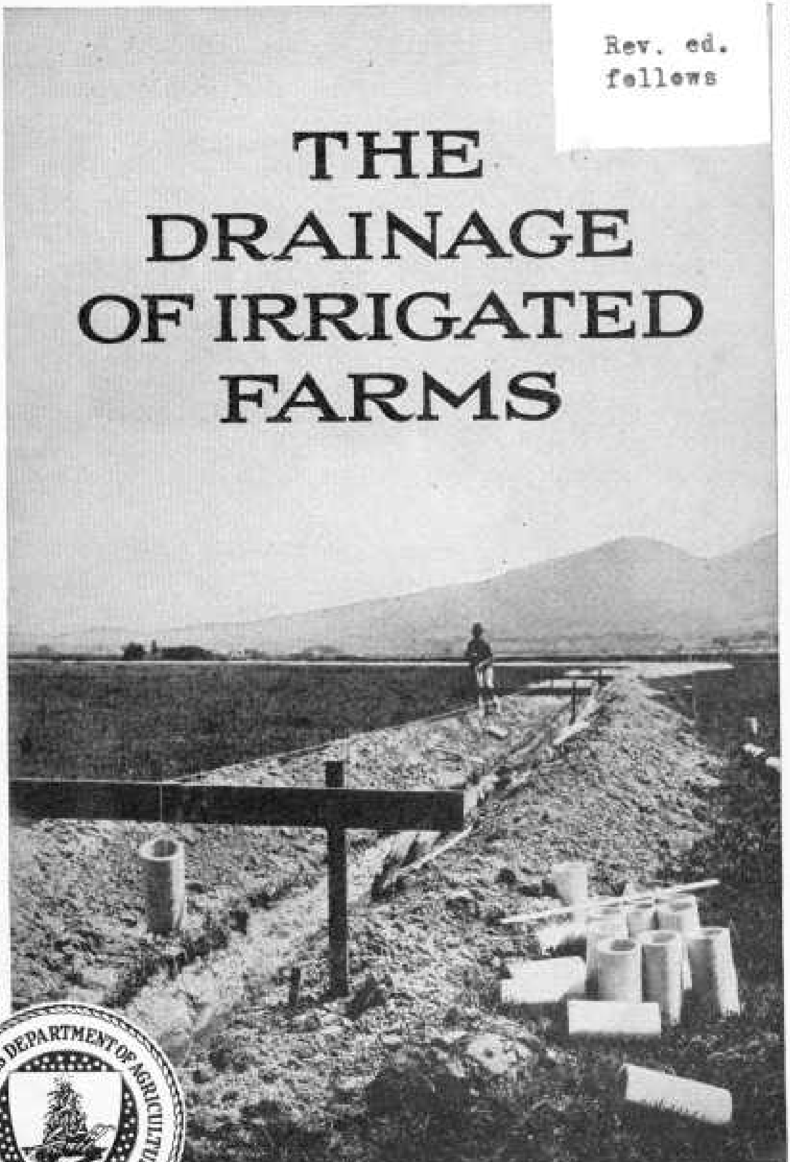
THE DRAINAGE OF IRRIGATED FARMS



MANY acres of irrigated land have become water-logged. These must be drained before they can be brought back into use.

Much irrigated land contains an excess of alkali salts, and underdrainage is the basis of the process for their removal.

Water which percolates deep into the soil following irrigation often raises the water table to the height of the plant roots, where it may remain to the detriment of plant growth. Underdrainage will remove this useless water. When the salt content is sufficiently reduced, water so removed may be used again in irrigation.

Seepage or storm water from adjacent tracts, or water released in the soil by spring thaws, may escape either through surface drains or through underdrains.

Underdrainage prevents the heaving of soil by frost, and permits its ventilation. It makes possible a warmer soil, permits deeper cultivation, and, by allowing the plants to develop a deeper and more complex rooting system, actually increases the available moisture in the soil, instead of decreasing it; by the same means it increases the available plant food.

Methods of draining irrigated farms are described in this bulletin.

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DRAINAGE OF IRRIGATED FARMS.

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CONTENTS.

NEED FOR DRAINAGE OF IRRIGATED LANDS.

THE drainage of irrigated lands differs from the drainage of wet lands in general in that it is undertaken to protect or reclaim from injury lands which have been reclaimed from their naturally desert condition at considerable expense and have been productive. The drainage of such land means not merely an addition to the productive area but the saving of the original investment in such land in the farm of which it is a part and in the water supply for irrigation.

Practically every valley where irrigation has been carried on for any considerable length of time has lands in need of drainage. Several classes of land in the irrigated section require artificial drainage in order to be fitted for crop production.

There are natural swamps, but these constitute a minor portion of the area under consideration. They are located chiefly near lakes or watercourses and represent surface accumulations of water. They usually are given over to tule growths, bulrushes, and willows.

Other naturally wet areas are those at the foot of mountains, benches and steeper slopes, produced by seepage from precipitation and from melting snows in the mountains or by springs fed from the same sources.

Of more importance than either of the foregoing, however, are the man-made swamps, the products of irrigation. The area of such

lands constitutes by far the greatest portion of the entire area in need of drainage. Lands accustomed to a very limited supply of water from natural precipitation have been drenched with water and subjected to additional supply by leakage from reservoirs, canals, and ditches. Some areas have been converted into veritable swamps; others have become waterlogged, so that they are impassable by man or beast and unproductive of useful vegetation; and still others have passed from a condition of high productivity to one fit only for wet pastures (fig. 1). These conditions are readily recognizable, and the need for drainage is evident, but the result of

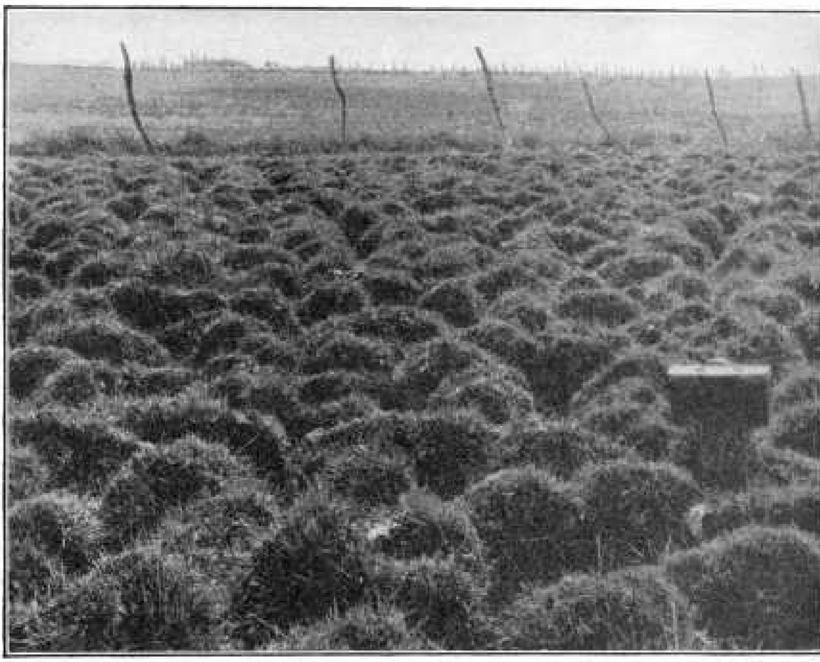

Fig. 1.—Bog produced by overirrigation.

overirrigation manifests itself often in an accumulation of alkali salts on or near the ground surface, without any apparent wetness (fig. 2). Drainage is the only cure for the latter condition.

Frequently the lands injured by irrigation are not those on which the water is applied, but lower-lying lands injured by the seepage from the higher land.

In addition to the foregoing there are natural alkaline areas that never have been farmed. The reclamation of these lands must be based on underdrainage.

BENEFICIAL RESULTS OF DRAINING IRRIGATED LANDS.

As the fundamental basis of all other benefits drainage removes excess water from the soil, whether on the surface or contained as free water within the pores of the soil (fig. 3).

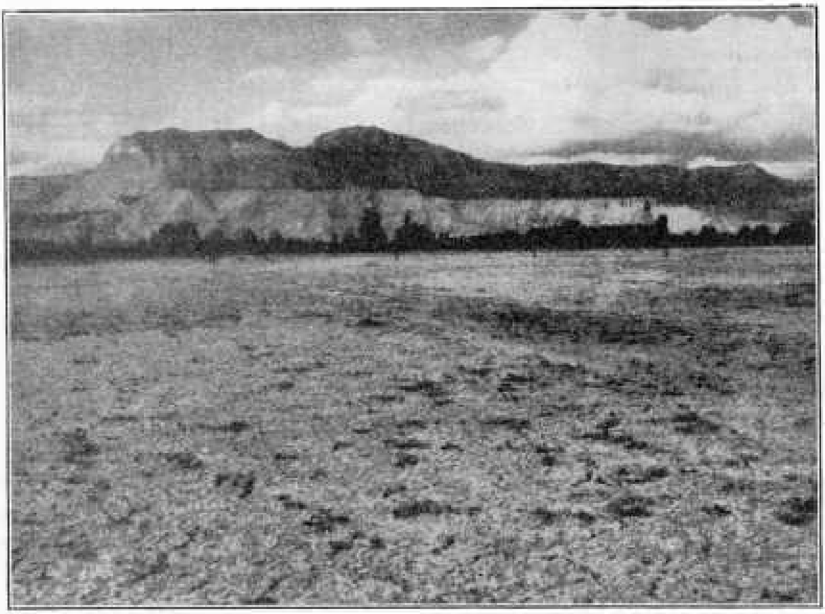

FIG. 2.—An alkaline barren absolutely devoid of vegetation, formerly cultivated but ruined by overirrigation.

FIG. 3.—Wet pasture after reclamation by drainage.

In many instances irrigated land contains an excess of alkali salts and underdrainage is the basis of the process for the removal of

these harmful salts. All of these salts are soluble in water and the soil water usually is charged with them so that in effecting its removal the salts in solution are removed. Where surface accumulation of salt powder or crystals has taken place, it usually is desirable to apply water artificially to leach out the salts (fig. 4).

Precipitation, which plays such an important part in drainage problems in humid sections, is of little importance in the irrigated section, but there are occasional heavy rains that are capable of doing damage by raising the ground-water table at just the wrong time.

Of far greater importance than precipitation is the water lost by deep percolation following irrigation. In undrained soils this often brings the water table up around the plant roots where it may remain

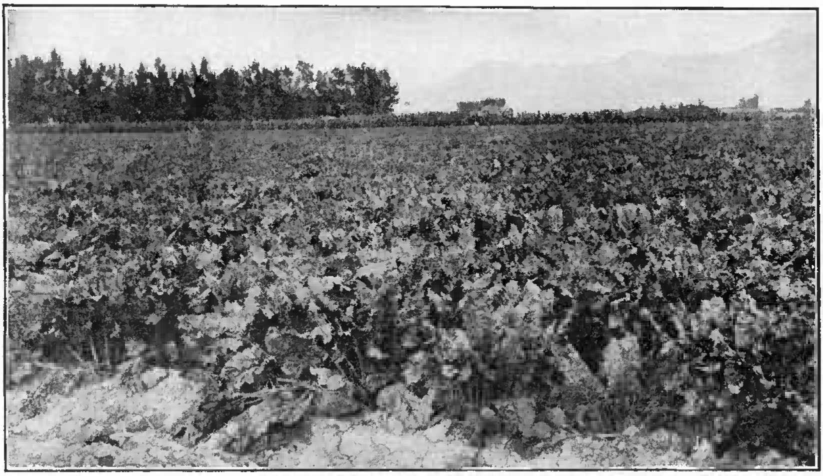

FIG. 4.—Sugar beets growing on formerly alkaline tract reclaimed by drainage.

for a dangerous length of time. Underdrainage will take care of such excess unless unusually wasteful methods are used in irrigation.

Water making its way onto a tract by waste or seepage, or storm water from an adjacent tract, may be taken care of without injury to the tract by underdrainage supplemented by surface drainage, if desirable.

A sudden change of temperature in the spring often supplies a surplus of water by the melting of snow or of frozen ground. Underdrainage takes off such water.

Underdrainage also prevents the heaving of soil by frost.

It is manifest that air and water can not occupy the same space at the same time and that water, being heavier, will crowd the air out of the soil pores. It is well known that for proper plant development the presence of air in the soil is as important as a supply of moisture. When underdrainage is installed and the excess water

moves downward, the air is admitted into the soil and the proper balance between the air and moisture content is restored.

When organic matter decays in the absence of air, as in water-logged soils, gases and other substances are sometimes formed which are injurious to plants. This is avoided by underdrainage, which enables the air to enter the soil.

It takes much more heat to raise the temperature of a given volume of water one degree than it does to raise the temperature of the same volume of air to the same extent. Underdrainage makes possible a warmer soil. This result is of importance at all seasons of the year, but particularly so in the early spring. Underdrainage induces earlier germination and the season is made both earlier and longer.

Another early spring advantage of underdrainage is that plowing may be done much earlier and with greater ease.

Underdrainage improves the texture of the soil itself by developing the drainage pores, producing flocculation, promoting root development, permitting deeper cultivation, etc.

Underdrainage increases the available depth of soil, which is equivalent to increasing the available acreage without adding materially to the amount or cost of manipulation.

Underdrainage provides a control over irrigation and permits a more economical use of water, preventing surface waste when large heads are used.

Underdrainage increases the available moisture in the soil itself instead of decreasing it, as is feared by many. This is due to the fact that the plants develop a deeper and more complex rooting system which comes in contact with a greater number of soil particles and consequently a greater surface of water film area.

For the same reason underdrainage increases the available quantity of plant food.

Deep rooting in the spring also insures against drought. Plants growing on drained soil are not so liable to injury due to water shortage in the summer. This is of special importance on tracts that have late water rights, since crops are more likely to be matured before the supply is cut off; but failing this, they have an increased underground supply of moisture due to underdrainage.

Beneficial bacterial activity is largely suspended in cold, wet soils, and such activity is necessary to the manufacture of plant food and its conversion into available form. Underdrainage increases the zone and intensity of such bacterial activity.

The water developed by underdrainage is brought to the ground surface where it is available for reuse either by the owner or by others to whom it may be rented or sold. Drainage water, even from tracts that have been salty, may not be injurious if used on drained

land, since the salt content is reduced rapidly to a safe percentage, but this should be determined before such water is used.

SUBSURFACE INVESTIGATIONS.

To determine the various factors of design it is necessary to make a careful study of subsurface conditions, often to a depth of many feet. Subsurface studies may be made by means of test pits and borings. On account of the high cost of test pits, only a few will be dug ordinarily, but it is customary to make a large number of borings. Test pits may be dug with shovels and picks if necessary; but usually it is feasible to use telephone shovels and spoons and make a hole only a foot or so in diameter. A test pit affords a much better idea of the subsoil than a boring and is especially useful in giving an idea of the drainage capacity of the soil. For determining depth to the water table, fluctuations of the latter, depth to and the thickness of various substrata, a boring is nearly as satisfactory. It is even possible in this way to obtain a fair idea of the character of the various strata. Borings may be made with an auger consisting of a carpenter's bit welded to a half-inch gas pipe, provided with a handle consisting of a T and two short pieces of gas pipe. The gas-pipe stem should be cut in 4-foot lengths so that it may be extended as the depth of boring increases. The screw tip and the sharp wings should be removed from the bit. Figure 5 shows such an implement. Care must be used to secure the type of bit shown, as an ordinary twist bit is not satisfactory.

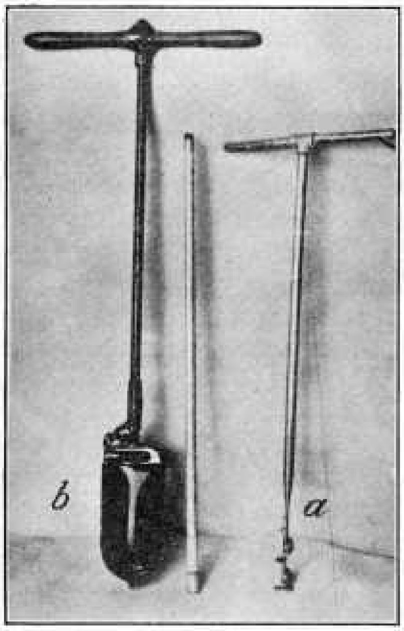

FIG. 5.—*a*, Soil auger suitable for making test holes. *b*, Earth auger suitable for boring observation wells and relief wells. The latter is adjustable and the jaws open for discharging the dirt.

In making soil borings only a turn or two should be given at a time, the soil being removed and examined by augersful. The character of the soil may be determined by the way the auger cuts, the difficulty in pulling it out, the way the soil holds together when being removed from the auger, and by rubbing the soil between the fingers or gritting it between the teeth.

If it is desired to observe the behavior of the ground-water table over a more or less extended period it will be necessary to install observation wells. These may be bored with an earth auger or a post-hole auger (fig. 5), and ordinarily must be lined to prevent filling. The most suitable casing is made of ordinary galvanized downspouting perforated at frequent intervals on several sides with a nail. The casing should extend a half foot or more above the ground level and should be capped or provided with a plug. A round block of wood should be fitted into the lower end to prevent mud from rising in the casing. In the case of a gravel subsoil an ordinary well point screwed onto a length of iron pipe serves admirably.

A number of such wells should be installed on most irrigated farms so that the owners may have immediate notice of coming injury and be prepared to combat it before crops are lost and before soil conditions become bad, making construction costs much higher than they should be. Men have declared frequently that the ground water on their farms was not within 20 feet of the surface when, as a matter of fact, it was within 2 or 3 feet.

Every irrigated farm should be supplied with a soil auger such as that described above, and it should be used intelligently in connection with irrigation practice. Many farmers in the irrigated section consider a soil auger of as great importance as any tool or implement they possess.

The making of subsurface studies for the actual design of a drainage system, however, ordinarily should be left to some one trained in drainage work, as there are few projects so small or apparently so simple as not to warrant the employment of such a person. Surveys must be made in order to design an economical and efficient system, and it is preferable that the subsurface studies be made at the same time so that the surface and subsurface data may be correlated properly.

REQUIRED DEPTH OF DRAINS.

One of the first questions asked by the landowner contemplating drainage of irrigated lands is "How deep should the drains be?" The matter of depth is one of the most important factors, but a depth perfectly satisfactory in one case may render a drainage system unsuccessful in another. In general it may be said that drains in the arid section must be deeper than those in humid soils. The soils themselves usually are deeper and the plant-root systems extend to greater depths. But more important than either of these considerations is the fact that most irrigated soils contain salts that are harmful to crop development when present in excess on or near the ground

surface. These salts may become concentrated on the ground surface, even though the depth to the water table be several feet. The soil moisture rises several feet above the free water table in the soil, and this moisture is charged with harmful salts wherever the ground water contains such ingredients. The harmfulness depends in a large measure upon the concentration of the soil solution, so a given amount of salt may become harmful if transpiration or evaporation removes a portion of the water and leaves the salts. It is important, therefore, to lower the water table deep enough that the plant roots will not feed in salty solutions. The height to which water will rise by capillary attraction varies with the kind of soil, being greater in the case of fine-grained, compact soils than in loose, coarse-grained soils. The height of rise in clay often is twice as great as that in sandy loam. If the sand be very fine, however, the height of rise may be nearly as great as in clay. Experience throughout the entire arid West leads to the conclusion that drains rarely should be placed at depths less than 6 feet; that is, the distance to the water surface in the drains should not be less than 6 feet.

The subsoil is almost never homogeneous, however, and any change in formation has an important bearing on the required depth of drain. This is true whether the change is from a compact to a loose formation or vice versa. It is especially true if a stratum of either more or less pervious material is found within, say, 10 feet of the ground surface. For instance, assume that the tract under consideration is injured by seepage from higher land; that the first 2 feet of soil consist of loam, the next 4 feet of clay, and that under the clay is a layer of sand a foot thick, followed by more clay. The depth to the top of the sand is, therefore, 6 feet, and if a drain is installed 6 feet deep it will lie on top of the sand layer. As may be expected, the damaging water seeping from the higher land moves through this sand layer, therefore the drain fails to intercept it and the drainage system is a failure. Moreover, the sand makes a very unstable foundation for a drain and the tile is likely to get out of alinement, off grade, or even to be up-ended and filled with sand. Even if none of these things happens, there is great danger of sand and silt making their way into the tile and obstructing it. It is quite evident that the drains should be laid on the clay underlying the pervious stratum or perhaps be bedded slightly into the clay. In that case there would be no danger of the tile getting out of position and the drain would be very effective. Thus an additional foot in depth often makes the difference between success and failure. It is necessary to know the existing underground conditions in each case before the proper depth can be decided upon.

Much the same situation would arise if the soil were a sand with a hard, impervious layer at 7 feet. Water reaching the tract by

seepage from higher land would be likely to move along the impervious layer, and if a drain be laid at a depth of 6 feet the water would continue to pass under it and the tile would be likely to become displaced and obstructed. Manifestly the correct practice would be to lay the tile on or slightly in the hard, stable stratum.

Even if the soil be homogeneous the question of depth is of great importance. In such a case the effectiveness of the drain increases with the depth. A line drawn along the surface of the water table from one drain to the next is a curve which rises rapidly away from the horizontal near the drains, but is very flat midway between drains (fig. 6). If the depth of the drains be increased the depth to this curve is increased at every point, but not equally so. Thus with drains at a given distance apart, the drainage is improved greatly over the whole area, or the same minimum depth may be obtained with the drains placed farther apart. It becomes a plain economic problem, therefore, and costs must be compared carefully to determine whether a few expensive, deep drains are cheaper than a greater number of comparatively shallow drains. Drains 8 to 10 feet deep, and even more, have been installed, but their cost has been so much greater per unit of length, and the difficulties of construction have been so much more serious, that, although they have been more effective, requiring fewer lines, it is questionable whether they have been more economical. Suitable trenching machinery is limited to a trenching depth of 8 feet, and unless some special condition exists which necessitates a greater depth it is recommended that the depth of drains be kept within this limit.

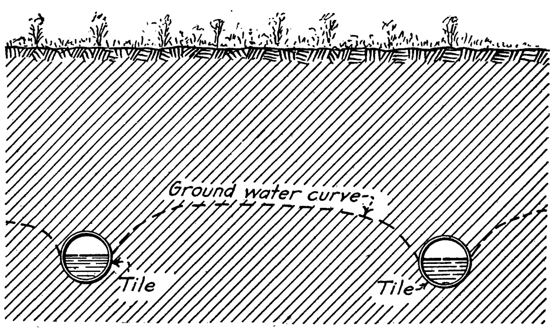

FIG. 6.—Cross section through soil, showing profile of ground-water surface between drains.

It is not always true, however, that the effectiveness of a drain increases with the depth. For example, in a subsoil that changes from a sand to a compact, relatively impervious clay at 6 feet, it would not be wise to install drains at a depth of 10 feet since they would then be laid in material that yields very little water, and the effectiveness of the system would be little greater than if the drains were installed only 6 or 7 feet deep, and the expense of the extra cutting would be wasted. There is even a possibility that the drains would be ineffective at such a depth. If the subsoil is a joint clay, however, it will be found to drain as readily as sand.

Drains having a depth of from 2 to 4 feet, such as are employed in humid sections, are practically worthless in the reclamation of irrigated lands.

SPACING AND LOCATION OF DRAINS.

The landowner contemplating drainage invariably asks the question, "How far apart should drains be placed in draining irrigated lands?" This question, like that as to the proper depth of drains, does not admit of a definite answer. The question is more one of location than of spacing, and the two factors must be considered together, the latter usually depending largely on the former.

The damaging water may have several sources of supply and, as likely as not, it will be moving laterally through the soil instead of percolating downward from surface application. The chief sources of supply, aside from direct precipitation and the melting of snow on the ground surface of the tract itself, are downward percolation of the excessive water used in the irrigation of the tract itself, surface run-off from higher land, supplied as precipitation, melting snow, irrigation or seepage brought to the surface; lateral underground seepage from the irrigation of higher lands, and losses from ditches, canals, and reservoirs; and, in some instances, direct natural seepage from the mountains.

Ordinary drainage methods would serve for the removal of the moisture applied directly to the tract itself, from whatever source, but this constitutes the smallest part of the problem. In the majority of instances it is necessary to intercept lateral seepage from higher lands before the damaging water reaches the tract in question. Often a combined system is necessary.

In the interception of lateral seepage the question of location is of highest importance, while the question of spacing is of little or no consequence. One properly placed line of drain will be more likely to reclaim successfully the injured area than a dozen lines placed at random, however closely they may be spaced. It is not unusual to find that a single drain will reclaim a 40-acre tract, when it can be located so that it will intercept the damaging water along the line of its appearance as seepage. For instance, consider a tract of land injured by seepage from higher land. The seepage appears usually along a belt at the change of slope from a steep to a lighter grade. If the subsoil be examined, it probably will be found that there is a more pervious stratum of material, say sand, at a depth of several feet. This stratum of sand acts like a pipe line, leading from the source of supply and pouring the damaging water into the lower land, since the flatter slope is insufficient to carry the water away as rapidly as it reaches the tract. Now, if a drain is located just

below the line of the change of slope, at or near the upper edge of the wet area, and is at sufficient depth to cut through the sand layer, the flow of water will be intercepted and the water will be carried away in the drain without doing damage to the land. (See fig. 7.)

The conditions must be studied thoroughly and to a sufficient depth to make sure that there is no pervious stratum underlying the drain through which water may seep to the lower land. In case such a stratum exists at a depth of, say, 10 feet or more, it will not be feasible ordinarily to reach it with a drain line, but a drain of ordinary depth may be installed and relief wells bored in the bottom of the trench to the stratum, thus providing passageways through which the water may rise and reach the drain. (See fig. 8.)

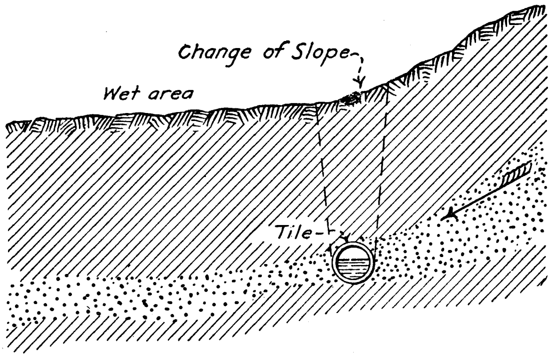

FIG. 7.—Drain properly laid to carry off seepage.

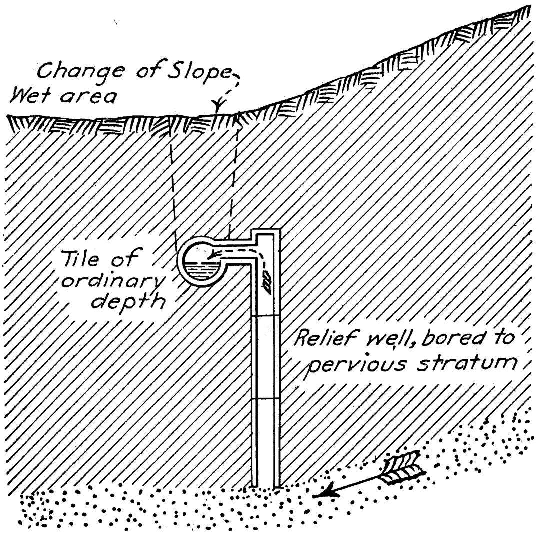

FIG. 8.—Relief well.

After an intercepting drain is installed and the seepage from outside sources is cut off the natural drainage of the tract usually is sufficient to take care of the water applied to the tract itself, but if this is found to be not the case it will be necessary to install drains to remove the excess water. The question of spacing may come in here, especially if the tract be rather flat and has a fairly uniform surface. If the subsoil be clay, with a sand stratum at a depth of several feet, drains 660 to 1,320 feet apart will serve. If no sand stratum be present it may be necessary to reduce the spacing to from

440 to 660 feet, but if the subsoil be sand the spacing may be greater than 1,320 feet, and in the case of gravel subsoil the spacing may be a half of a mile or more. Where the subsoil was a coarse gravel some very satisfactory systems have been installed with drains every half mile, with the depth from 6 to 8 feet.

If the tract in question be cut up by swales and depressions the installation of a regularly spaced system is not advisable. Generally, in such a case, the drains should be located in the swales. (See fig. 9.) The latter arrangement has some exceptions in cases where the subsoil underlying the swales is less pervious than that underlying the higher ground. Often it is necessary to have the drain lines run at the edge of the swales, two lines being required for each swale. (See fig. 10.) It has been found necessary in some instances to locate the drains on the higher land.

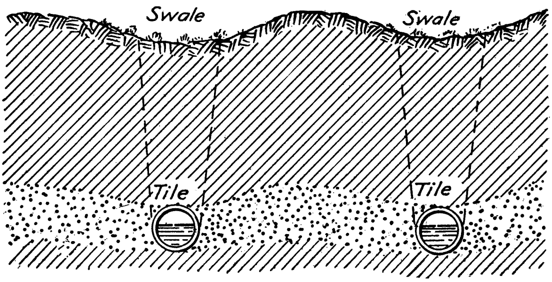

FIG. 9.—Cross section through soil, showing method of draining swales.

The installation of drains below the wet area, with the idea of drawing out the water, should be attempted only when the subsoil is a coarse gravel, and not even then if the land above the wet area has a greater slope.

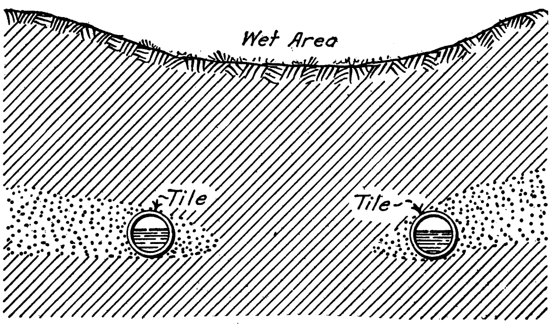

FIG. 10.—Cross section showing application of double line of tile. This is made necessary by the absence of pervious material underlying the middle of the swale.

As a rule drains in the irrigated section run across the natural slope rather than down the slope. The reason for this is that with the drains running down the slope the damaging water would be moving in the same direction that the drains run, and consequently very little water would reach the drains, the remainder continuing to reach the lower land and doing damage. The only land drained would be that in the immediate vicinity of the drain lines.

The average amount of tile per acre ordinarily employed in farm drainage in the irrigated section is about 66 feet. At this rate a

mile of tile will drain about 80 acres of land, or a square mile of land will require about 8 miles of tile.

TYPES OF DRAINS.

There are two general types of drains in use in the irrigated section—the open ditch and the covered drain. Since this discussion deals only with the individual farmer's problem, no consideration will be given to the large open canals used for outlets in community or district system. The open ditch, as its name implies, is merely a waterway cut into the soil so that it will receive the underdrainage from adjacent land. The covered drain consists essentially of an underground conduit for the collection and transportation of subsurface water. It is superior to the open ditch, except where grades are very flat or where the quantities of water to be handled are large. The chief reason for using the latter is largely one of economy, and a decision as to the type to be used should be made only after all factors having a bearing on the subject are considered carefully.

The open ditch itself takes up considerable space, and the material removed in building it usually is of such a quality that it is not wise to spread it over the surface of the adjacent land, so additional space is lost. Moreover, it is not safe to irrigate land close to such a channel, as there is danger of the water breaking into the ditch, with consequent injury to it and the land. Even a very small ditch may require that a strip of land several rods in width shall be rendered useless for agricultural purposes, so that an effective drainage system may reduce materially the available acreage of a farm. To keep an open ditch open the sides must be made sloping, not steeper than one horizontal to one vertical, and to prevent the growth of vegetation and the accumulation of mud, etc., in the channel from obstructing it the bottom width should be not less than 4 feet, except in gravel or stiff clay, where it may be 3 feet, so it becomes necessary to excavate much more material than in trenching for covered drains. But in spite of careful design, construction, and operation open ditches are sure to require a great deal of maintenance and repair, and the expense for these often amounts to more in the long run than the extra cost of covered drains.

Open ditches are unsightly and provide harborage for obnoxious weeds and breeding places for injurious and disagreeable insects. Their presence is a constant source of danger to farm animals. They cut up the farm into inconvenient and irregular shapes and require the installation of farm bridges and flumes in order to facilitate communication between the various parts of the farm and for the conveyance of irrigation water and waste water from tract to tract. Covered drains, on the other hand, are not subject

to these objections. They take up no valuable space, and if properly installed require little or no maintenance. The only way in which difficulty can occur, in connection with vegetation, is the possibility of water roots choking the drains, and this can not occur if lines are kept away from water-loving trees, and if such plants as the sugar beet are not grown directly over the drains.

In order to decide between types of drains, it is proper to add to the estimated cost of open ditches a sum sufficient to pay at current interest rates a return large enough to pay the annual maintenance, which often is 10 per cent of the first cost, and compare this total with the first cost of covered drains. For instance, assuming that the first cost of the open ditch would be 50 cents per foot and of the covered drain $1.25 per foot, if the maintenance cost is 5 cents per foot per year for the open ditch and the interest rate is 5 per cent, it will be necessary to add $1 per foot to the actual cost to pay for the maintenance. This makes the cost of the latter $1.50 per foot, as against $1.25 for the former. When the maintenance cost is considered, the covered drain often will be found actually cheaper than the open ditch, and when the desirability of the two is considered there is no comparison.

The most suitable material for use in a covered drain is clay tile. It should be hard burned but not brittle. The 2-foot length is the most satisfactory. The tile should be straight and truly cylindrical in shape. The walls should be smooth and free from serious cracks and blisters. The ends should be free from rough edges and irregularities. The tile should be uniform in size and thickness for any given diameter. The walls should have fairly uniform thickness at both ends and at various points of the circumference. They should be very impervious and have a low porosity. The material from which the tile is made should be free from foreign ingredients, particularly cinders and free lime.

Pole drains, brush drains, mole drains, rock drains, and cobble drains are almost useless in irrigated soils and never should be installed. Lumber box drains have been used to some extent as a substitute for clay tile, but their use is a doubtful economy. Cement tile as at present manufactured is not recommended for the drainage of alkali lands.

SIZES OF DRAINS.

The spacing of drains in the irrigated section usually is much greater than in humid sections, and frequently a single line of drain may effect the reclamation of a considerable acreage. From this it will be concluded that larger drains will be required in the drainage of irrigated lands. It has been found that they need not be pro-

portionately larger, however, since the amount of water which it it necessary to take care of is smaller for a given acreage. In the arid section there is likely to be a continuous discharge of drainage water throughout the year, and frequently the discharge is very uniform at all times. However, there are certain maximum flows, usually during the period of greatest irrigation application, and it is necessary to provide a drainage capacity that will take care of such flows.

If only the required capacity of the drain were considered, it would be found feasible to do a great deal of drainage with 4-inch and 5-inch tile, but experience has shown that the use of tile smaller than 5-inch is not satisfactory, while 5-inch should be used only for short branch lines or at the upper ends of branch lines. The following table is offered for purposes of comparing the carrying capacity of tile lines of different sizes, on the assumption that all are laid on the same grade.

Relative carrying capacity of tile of different sizes.

One—	Will carry the discharge of—
6-inch tile	Two 5-inch tiles.
8-inch tile	Two 6-inch tiles.
10-inch tile	One 8-inch and one 6-inch tile.
12-inch tile	One 10-inch, one 8-inch, and one 5-inch tile; or three 8-inch tiles; or seven 6-inch tiles; or twelve 5-inch tiles.

As a rule, tile larger than 12-inch in diameter is not used in individual farm drainage.

The size of tile required depends on the amount of water to be carried and on the slope of the drain. The latter can be decided upon when the survey of the land is made and the fall to the outlet is measured. The former is not so easy to determine. It depends on the location of the tract, the nature of the soil, the slope of the ground both on the tract and above it; on the quantity of water used in irrigation and on the method of irrigating, both on the tract and on higher land; on the rainfall and evaporation; on the seepage from reservoirs, canals, and ditches; and on many other factors. Indeed, the determination of the required capacity of a drainage system is the most difficult problem confronting drainage engineers, and demands their best efforts. Intricate measurements and calculations must be made in each instance. It is therefore impossible to give definite instructions in regard to this important matter. It is possible, however, to give a general idea of required sizes based on a wide experience under a great variety of conditions. The following table is intended to apply to fairly uniform land not located at the foot of steeper slopes or benches, nor in pockets or depressions, nor in flat

river bottoms where it will receive surface run-off from higher land, nor where it will receive water from deep sources by pressure. The assumed slope of the tile is 2 feet per thousand feet.

Sizes of tile required to drain given areas having different types of soil.

Area of tract (in acres).	Size of tile required.		
	Clay with sand stratum.	Sand.	Gravel.
320	10-inch		
160	8-inch	12-inch	
80	6-inch	10-inch	12-inch.
40	6-inch	8-inch	10-inch.
20	5-inch	6-inch	8-inch.
10	5-inch	6-inch	8-inch.

If the soil be compact clay, a given size of tile will drain larger areas than indicated. If the subsoil be joint clay, the "sand" table should be used. If the drain be located at the foot of a bench or in a gravel pocket, none of the above bases will apply. A better basis for design in such cases is the length of a given size of tile which it is safe to use. A slope of 2 feet per 1,000 feet is assumed, as before. The following table will give a rough idea:

Sizes of tile required for drains of different lengths.

Size of tile.	Maximum length.	
	Sand stratum.	Gravel.
	Feet.	*Feet.*
12-inch	5,300	1,300
10-inch	3,200	800
8-inch	1,800	500
6-inch	800	200
5-inch	500	100

For greater slopes smaller tile is required, and for flatter slopes larger tile is necessary, the variation in capacity being as the square root of the slope.

For open ditches the bottom width should be 4 feet and the side slopes should be at least 1 to 1. Thus for a depth of 6 feet the top width would be 16 feet or more, and for a depth of 8 feet the top width would be 20 feet or more.

In the installation of a drainage system it should be borne in mind that the improvement is permanent, and that after the tile is once covered up it is more expensive to uncover and relay it with larger tile than to install a new drain, so it is false economy to cut down on the size of tile. It is much better to err on the side of too great capacity than too small.

CONSTRUCTION METHODS.

In many instances owing to lack of humus the soils of the arid region are very fluxible when wet, and the construction of drainage systems is very difficult and requires painstaking care and ingenuity. Special methods and devices have to be employed, and special machinery has been developed.

Drain lines must be laid out carefully and grade stakes set. The completed drain must be true to grade and as straight as possible. For hand trenching it is advisable to stretch a cord on the ground along one edge of the proposed trench to obtain good alignment. To insure accurate grade at all points, grade planks should be set up at each station at a uniform height above the grade of the drain, as shown in the illustration on the title page. A stout cord then may be stretched over the middle line of the trench from plank to plank and every point on this cord will be the given height above grade. Grade may be established at one end of each tile with a grade pole having a length equal to the distance from the cord to the proper location for the tile. This may be accomplished by keeping the cord taut by suspending a tile or other weight at each end and measuring down from the cord at the desired points.

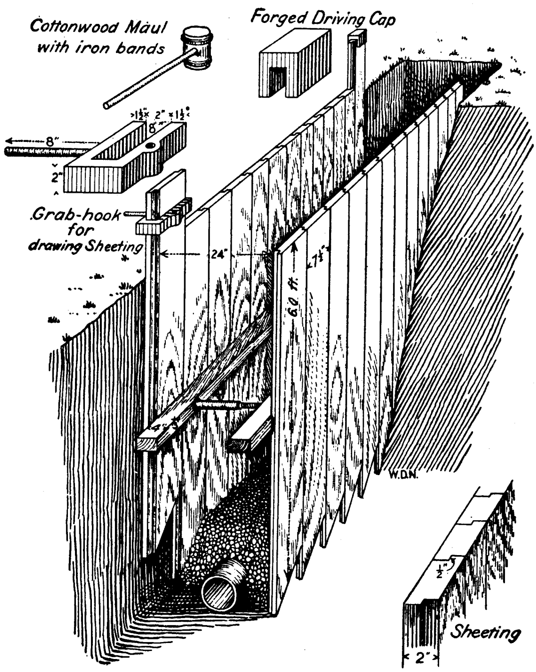

FIG. 11.—Showing shiplap sheeting and method of installation for drains 6 feet in depth in fluxible soils. For deeper drains, two sets of timbers and braces must be used.

Construction work always should start at the outlet of each line and proceed up the slope, so that the water developed will drain away.

In installing covered drains either hand labor or trenching machinery may be used. Frequently on small projects hand trenching is cheaper, but usually on larger projects machines can do the work more rapidly, economically, and satisfactorily. It is preferable to let a contract for the work to an experienced and capable contractor.

If hand labor is used it usually is necessary to operate with small gangs, ordinarily about a half dozen men to the line, as the trench must be opened from the top to the bottom as rapidly as possible and the tile laid and blinded before caving takes place. The men should work as closely together as practicable and not even the first spading should be taken more than a rod in advance of the tile laying. Each man should remove a spading, moving backward at the same time. The man removing the last spading should also grade the bottom. He should not step on the finished bottom and no one should stand near the edge of the trench, nor should wagons or material of any sort be permitted near the trench. The soil removed from the trench should be placed as far back as it conveniently may be. The tile should be laid at once and blinded by means of a few inches of earth caved from the edges of the trench. If the banks tend to cave off in large chunks or slabs it will be necessary to brace them apart with planks separated by stout crosspieces or trench jacks.

A very troublesome condition is that in which the presence of a wet, pervious stratum near the bottom of the trench causes a lateral and upward movement of the soil in the bottom of the trench. In such a case it is necessary to provide a tight cribbing to shut out the oozing material. A design for such a cribbing is shown in Figure 11. It consists of two heavy timbers, held apart by trench jacks, behind which is driven lumber sheeting properly matched and beveled at the lower ends to insure a tight fit. The sheeting may be driven by means of a heavy maul and may be removed with a three-legged derrick and a special grabhook like that shown in the figure.

If the soil in the bottom of the completed trench is so soft that it will not support a man's weight, wooden racks or cradles should be laid under the tile to keep it in line and on grade. If conditions are exceedingly bad it often is advisable to use sewer pipe in place of drain tile, as the bells aid in keeping the line intact. Second quality sewer pipe is suitable and generally may be purchased at about the same price as drain tile. Under ordinary conditions, however, the use of sewer pipe is not recommended, since the cost of freight and hauling is higher than for drain tile and it is heavier and more difficult to handle. Also in stable ground it is necessary to dig out places for the bells, which considerably increases the cost of trenching.

Tile should be laid with extreme care. The joints should be as close as possible, and if the soil is semifluid and contains much fine sand and silt it will be necessary to provide some means of keeping the oozing material from entering the tile joints. Almost all the water entering tile lines makes its way through the joints, practically

none entering through the walls of even the more porous tile, so the covering for the joints must provide for the ready passage of water. Straw makes a very good filter when new, but it is likely to decompose and form a sticky, impervious mass over the joints. Brush and willows are not satisfactory and render any subsequent removal of the tile very difficult. Graded gravel, ranging in size from sand to pebbles an inch in diameter, makes an excellent filter, but it is not always available. Cinders also are satisfactory. Strips of burlap wrapped about the joints give good service temporarily. The custom of merely laying strips of building paper over the tops of the joints can not be commended, since the greatest tendency is for the sand and silt to enter at the bottom of the joint. Wide strips of heavy tarred roofing material should be wrapped entirely around the joint, or a wide strip of the material should be unrolled onto the bottom of the trench, as the tile is laid, and then strips laid over the joints, joining the longitudinal strip, after which the filter material should be placed around and over the joint.

The more pervious materials should be placed adjacent to the tile.

The backfilling may be done with a plow with three or more horses and a long pole evener, or with a scraper, road grader, or go-devil. Recently power backfillers have been placed on the market. All the soil should be returned to the trench and be banked up over it, so that future settling will not leave a depression over the drain.

In machine trenching it generally is necessary to draw a portable shield after the machine in which the tile may be laid and blinded before caving takes place. Figure 12 shows such a shield in use in trenching in unstable soil. This illustration also affords an idea of the depth of drains required for reclamation of irrigated land. The man in the shield is standing on top of a 15-inch tile. There are several types of suitable trenching machines, but as machine work usually is let by contract, the choice of type must be left to the contractor.

DEVICES.

Bulkheads and outfalls.—The outlet of a drainage system should come in for more consideration and attention than usually is given to it. If the tile line discharges into a deep ravine or river channel at some distance above the water level an outfall should be provided. This may consist of a corrugated iron pipe extending far enough out over the bank to discharge the drainage water directly into the stream without striking the bank and causing erosion. The other end should be anchored by means of a concrete wall and a careful connection with the tile line must be made so that water will not

find its way along the outside of the conduit. The last few joints between tile should be cemented.

If the drain discharges at or near the water level or bottom of a channel a concrete, brick, or timber bulkhead should be constructed to prevent injury from frost and from the caving of the banks, and to prevent the washing out of the tile line at the lower end. Care should be taken that it has a good foundation, in order that it may not be undermined. Figure 13 shows a cheap and easily built concrete bulkhead. A network of heavy wires or small rods of copper

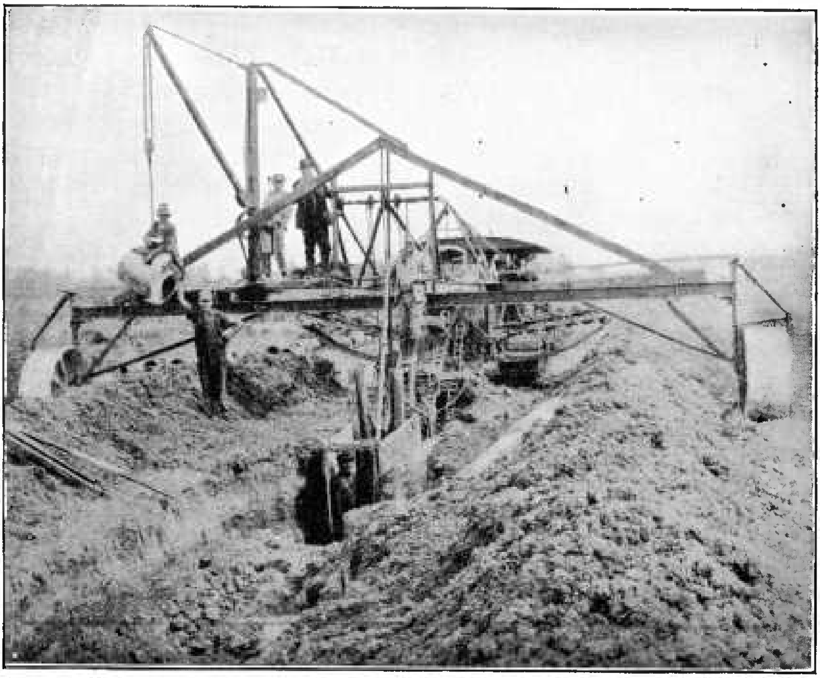

FIG. 12.—View showing trenching machine provided with caterpillar traction and portable shields for use in fluxible soils. Note the additional broad wide-spaced wheels at back which support the cutting unit and shield.

or galvanized iron should be placed across the outlet to keep out small animals. A length of corrugated-iron pipe makes a very satisfactory outlet for a tile drain.

Manholes.—A change in direction of a line of tile should be made gradually by a smooth curve, or a manhole about 4 feet across should be installed at the point of change. If the soil contain much fine sand, a combination manhole and sand trap should be located at such a point, as well as at every change from a steep to a lighter grade. Such a device serves as an observation well in which the flow may be seen and the general conditions of the system watched. It also serves as a settling basin for any sand or silt that may be carried by

the drain, and if the trap be made to extend a foot or two below the drain, a chamber is formed in which a considerable amount of sediment is held until it can be removed. The manhole may be provided also with a surface inlet to make it possible for the drain to take care of surface water and, if desired, to provide for flushing the drain. As a manhole proper it provides a means for the operation of a root-cutting or drain-cleaning device operated by sewer rods. If it is expected that such work will be necessary, the drains should be laid out in straight lines with grades as uniform as possible, and a manhole should be provided at each junction, change in slope from steep to a lighter grade, and on straight sections at intervals of not to exceed 500 feet.

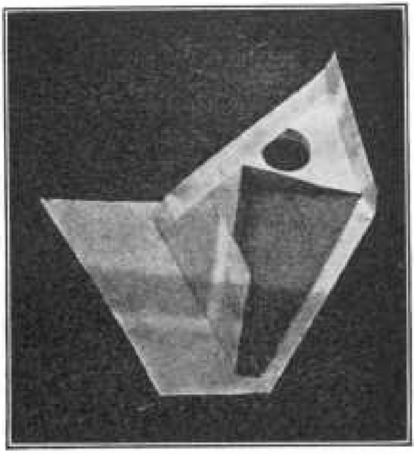

FIG. 13.—Concrete bulkhead for use at outlet of tile drain.

The most suitable manhole is built of corrugated-iron pipe, as shown in Figure 14, but lumber is often used. When built of lumber, 2-inch material should be used. Figure 15 shows a simple type of manhole, constructed of lumber and so designed that the earth pressure will maintain it in spite of the failure of the nails. In most places the manhole should be provided with a bottom and it always should be fitted with a cover that can be locked down.

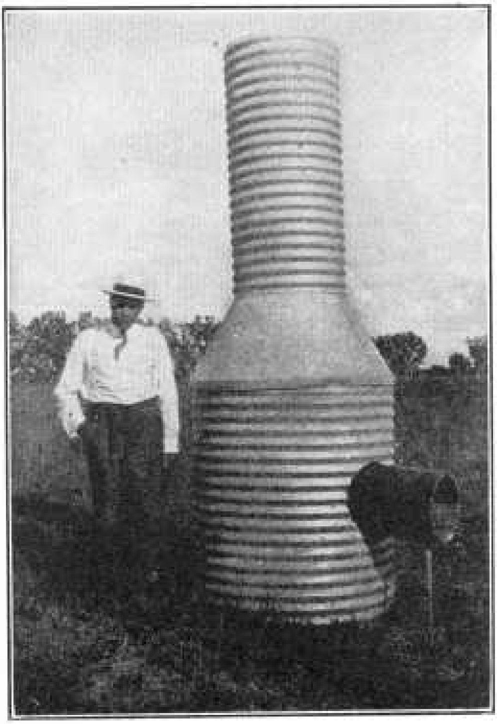

FIG. 14.

Observation wells.—If little sand be present, rendering sand traps unnecessary, it still is desirable to provide for observation of the

flow at points throughout the system. Nothing serves this purpose better than a vertical stack of large-sized second-grade sewer pipe, extending from a little above the surface of the ground to a foot or more below the tile line, and having holes cut in the lower length to accommodate the drain. Such a device is shown in Figure 15. As may be seen, a small settling space is provided, from which sediment may be removed with a telephone spoon. A cover always should be provided and the joints should be cemented. This device costs little and occupies small space. If desired, the top section may be removed subsequently, a cap provided for the second section, and cultivation be carried on directly over the top. Such a device also may be installed for inspection purposes between regular manholes.

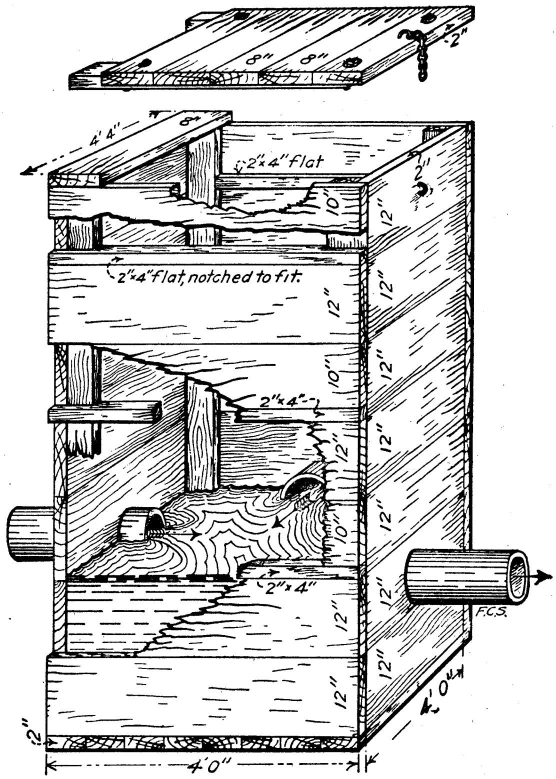

FIG. 15.—Combination manhole and sand trap with cover that does not depend upon nails to hold it together.

Surface inlets and flushing wells.—A vertical stack of pipe is useful also as a surface inlet or flushing well. Figure 17 shows how it should be installed. The bottom should be paved with coarse gravel and the top provided with an iron grating and a mound of gravel or crushed stone. The backfill should be well compacted around the stack. Such an inlet should be installed wherever a drain crosses a depression or flat, so that the waste water or storm water may not pond long enough to puddle the soil or "burn" the crop. During irrigation the entrance of water may be prevented by throwing up a circular ridge of earth around the mound. One of these devices also should be used at the upper end of each branch line. The first few lengths of tile in the drain should be a size larger than the tile designed for the drain, so the water will not be retarded in its progress into the drain.

Flumes.—Flumes should be provided for all canals and ditches that cross above underdrains, and care should be taken to prevent large quantities of water from flowing across drains, particularly during the first few seasons after the installation of the system.

Relief wells.—The source of damaging water often is in some deep, pervious stratum, and the movement is upward. The stratum is connected with a higher-lying source of supply, and the water is under pressure. Ordinary methods of drainage avail little since the damaging water rises between drains however closely they may be spaced, and it is not unusual to find water standing on the ground surface within 10 feet of a drain 6 feet or more in depth. The source of the water may be in gravel, sand, stratified shale, sand rock, or lava. A pressure condition has been found even where the only change in subsoil conditions was in the nature of the clay strata.

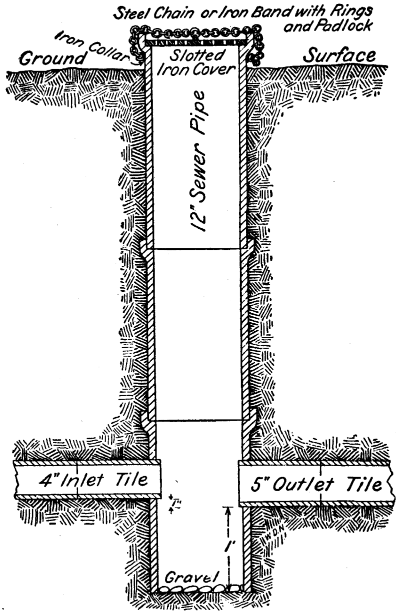

FIG. 16.—Observation well and sand trap constructed of pipe.

To meet the condition it is necessary to install relief wells connecting the pervious stratum with a tile drain laid at ordinary depth. The pressure causes the water to rise through the relief wells which act as vertical drains. The sole purpose of the ordinary drain is to carry off the water brought up by the relief well, and it accomplishes little or no direct drainage. Figure 18 shows a relief well in the bottom of a trench. The tile had not been installed when the view was taken. With the pressure relieved at the drain level the damaging water no longer can make its way to the ground surface within the area affected by the well or system of wells. It is necessary in each case to determine the required number and spacing of the wells and the best indication is the effect of one well upon another.

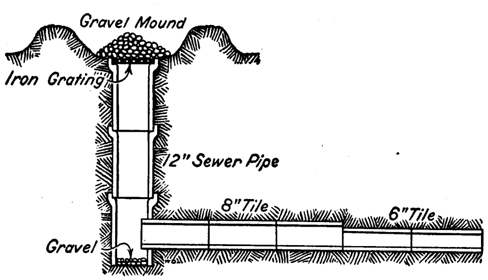

FIG. 17.—Surface inlet and flushing well built up of large tile and sewer pipe.

An earth auger may be used for the installation of relief wells in ordinary soil, but in shale or rock it is necessary to use a well-drilling outfit. Often it is necessary to drill to a depth of from 20 to 50 feet. Usually relief wells must be cased. A vertical stack of tile or an iron pipe may be used for this purpose. Wooden tubes also have been employed. The casings should be connected carefully to the drain line so there will be no danger that they will silt up in periods of inactivity.

FIG. 18.—Relief well in bottom of drain trench.

COSTS.

Owing to the great variety of conditions met in the drainage of irrigated lands, the cost of such work varies over a wide range. Chief among the many factors influencing cost are the size of the tract to be reclaimed, its relation to surrounding tracts, the degree of wetness, nature of the soil, type of drain installed, opportunity of obtaining an outlet, availability of materials, distance from factories and from railway connections, quality and cost of labor, feasibility of using machinery, season in which the work is done, knowledge of the man in charge, and method of handling the construction work.

Experience in practically all the Western States, under many different conditions, shows that the cost of draining ordinary-sized farms having an average soil that is neither so hard as to require picking nor so soft that serious caving of the banks of trenches will take place, ranges from $15 to $45 per acre, with the average $30 per acre. If hardpan, rock, or shale be present, or if the soil be fluxible, the cost may run up to $50 per acre, or even more if much tight sheeting of the trenches is necessary. In a few special cases drainage of small tracts in the midst of unreclaimed lands has cost between $75 and $100 per acre, but these costs represent situations that would not be encountered in regular operations.

In regard to costs per unit of length of drain it may be said that clay tile at the factory ranges in cost from about 2 cents per inch of inside diameter per foot of length for the smaller sizes up to about 2½ cents in the larger sizes. Hand trenching for tile up to 12 inches in diameter, under ordinary conditions, ranges in cost from 15 to 25 cents per linear foot for an average depth of 6 feet, with the cost increasing about 50 per cent for each additional foot, while trenching in hard or fluxible material will run up to more than 25 cents per foot for 6-foot trenching. Rock work would of course be much higher. When tight sheeting is required the work will cost 50 cents or more per linear foot. Machine trenching usually is cheaper than hand trenching.

ALKALI RECLAMATION.

It has been stated that underdrainage is the basis of the reclamation of alkali or silt lands, and the fact has been pointed out that drainage alone often is ineffective for complete reclamation and that subsequent treatment is necessary. The salt content not only must be reduced to a safe percentage, but it may be found that the presence of the salts has injured the physical texture of the soil and perhaps destroyed the humus content. Humus must be restored, evaporation must be reduced so that the future rise of salts may be prevented, and the tilth of the soil must be improved.

If expedition be desired in the removal of salts, or if natural precipitation and irrigation are insufficient to effect a satisfactory reduction in the percentage, a good-sized stream of irrigation water should be turned on the land and allowed to percolate through the soil as rapidly as possible. This is best accomplished by dyking the land into checks and ponding the water as deeply as feasible, each check having as large an area as the slope of the ground and the amount of available water will permit. In no case should an attempt be made to flush the salts from the surface. They must be leached out and carried downward in solution to the underground reservoir. The desirability of using large checks and liberal quantities of water is due to the fact that capillary attraction is equally effective in all directions, and it is necessary to offset the tendency of the salts to move laterally in the soil and reappear on a higher or dryer portion of the tract. For this reason it is required to make sure, in flooding, that all the surface is covered, even if knolls and ridges must be leveled first. It is advisable generally to cultivate a field thoroughly before the leaching process, but in some cases it has been found to be more satisfactory to flood first and then cultivate as soon afterward as possible. If the subsoil be so impervious that the leaching water does not percolate readily, it may be necessary to resort to subsoiling or blasting.

The following actual example of reclamation is offered to demonstrate the principles that have been stated:

Before drainage the ground water on a certain tract stood within 2 feet of the surface, which was covered with a white crust of alkali salts. Nothing of value grew on the tract, the only vegetation being an occasional salt weed. The average salt content for the first 4 feet of depth was 2.25 per cent of the soil. A drainage system was installed and in a month's time the excess water in the soil had run out, so that the ground water table was practically down to the level of the drains. This excess water contained a great deal of salt in solution, so that analyses made at the end of the month showed that the average salt content for the 4 feet had been reduced to approximately 1 per cent. The ground surface was cultivated and irrigated with a limited supply of water and some crops were planted, but gave only fair results. Meanwhile the higher temperature of summer had increased the evaporation and it was found that the average salt content for the 4 feet increased to 1.28 per cent in spite of the drainage. A near-by uncultivated and unirrigated spot which had been affected to some extent by the drainage system showed an average salt content for the first 4 feet of 1.51 per cent. It was evident that drainage alone would never reclaim the tract, so a heavy flooding was given it with the result that the average salt content for the first 4 feet was reduced to 0.43 per cent, which is less than one-fifth of the original content. At this time the near-by uncultivated spot showed an average salt content for the first 4 feet of 1.73 per cent, an increase which was due to the flooding of adjacent land while the spot itself remained dry. Further irrigation of the drained tract will reduce the salt content on the tract and increase that on the uncultivated spot. The results of this experiment are shown graphically in Figure 19.

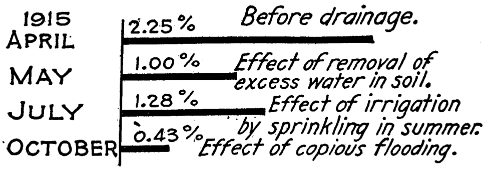

FIG. 19.—Diagram showing typical reclamation of alkali lands. Quantities are percentages of total salts in first 4 feet of soil.

Land should be cropped as soon as possible after reclamation; some crop which will shade the ground is preferable. If possible, the plants should be more or less alkali resistant. It must be kept in mind that the harmful salts are brought to the surface of the ground in solution by the capillary action of the soil and that they are deposited upon the surface when the solution is evaporated; hence the advisability of planting shading crops which reduce the evaporation. Artificial or soil mulches accomplish the same thing, and if shading crops are not planted the soil should be kept well

stirred. Subsoiling, in addition to assisting the leaching water to percolate to the drains, breaks up the capillary columns and retards the upward movement of salts.

Copious amounts of water should be used in irrigation and the water should be spread at once over as large areas as possible, making sure that the ground is covered as uniformly as may be. Waste water should not be allowed to run off the tract, as it is only the water that percolates downward that removes an appreciable amount of salt. However, water should not be allowed to pond in depressions or elsewhere for any considerable time after the head is turned off. If there is a tendency for the water to pond in this manner, either the depressions should be leveled up or surface inlets to the drain lines be provided, so that the excess may be removed in a short time.

Alfalfa and sugar beets are fairly resistant to the effects of alkali salts and shade the ground surface well. Alfalfa is a valuable crop anywhere in the irrigated section and sugar beets are being planted over a large portion of the West. Sweet clover, while not so valuable a crop, is very useful in reclamation work. All of these crops may be used in restoring humus to the soil. Grains do fairly well, barley being the most resistant, but they do not offer much shade or add greatly to the humus content of the soil when plowed under. For best results grain should be planted in the fall so that the plants may become sturdy before the salts become concentrated on and near the surface the following spring. It has been shown by Thomas H. Kearney [1] that the cane sorghums, and to a less degree the grain sorghums, are adapted to use on reclaimed lands.

MAINTENANCE.

If an underdrainage system be of proper design and construction, the matter of maintenance is of small consequence. If silt has accumulated in the tile lines during construction they should be cleaned out before the job is accepted. Irregularities due to the settling of the backfill should be corrected so that irrigation water will have no opportunity of making its way directly into a drain line. Vegetation that is likely to develop roots in the tile and obstruct the drains should be removed from the vicinity of the lines. Silt may continue to find its way into the tile lines for some time. This will be caught in the sand traps and should be removed from time to time.

In cases of serious obstruction of the tile by sediment or by the growth of roots, the conduit may be cleared with special cleaning devices, a number of which have been developed. These are very useful during construction in keeping the suspended matter in mo-

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[1] Kearney, Thomas H. The Choice of Crops for Alkali Land. U. S. Dept. of Agriculture, Farmers' Bulletin 446, pp. 20–21.

tion near the point of laying until sufficient water is developed to carry the material along. After the system is put in operation they may be used to clean out such roots as may have penetrated the tile line through the joints or to clear the line of obstructions caused by sand and silt. One of these devices is in the nature of an auger, while another is built like a small hoe. For the removal of roots an apparatus involving a spiral cutter is used, or, better still, a sort of wire brush. The latter is also useful in removing other obstructions and may be made easily by wrapping a piece of leather belting around a cylindrical wooden rod, first having driven the belting full of nails of such length that the outside diameter of the completed brush is somewhat smaller than the inside diameter of the tile to be cleaned. A still simpler device, and one that has proved very satisfactory, is a bunch of barbed wire. These devices may be operated most conveniently by means of jointed sewer rods. The latter are made up in 3 or 4 foot sections, fitted with couplings so arranged that they may be joined when two sections are placed at right angles,

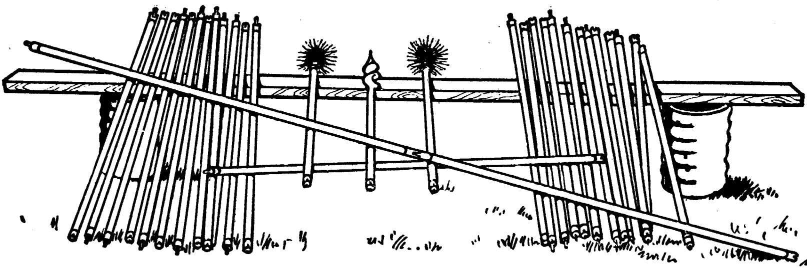

FIG. 20.—Sewer rods and tile-cleaning devices.

and are locked together when the two sections are in line. Working in a manhole 4 feet across, a man can easily put together and operate several hundred feet of rod in a tile line. Figure 20 shows a set of sewer rods and cleaning devices that have given satisfaction in operation.

The operation of drainage systems should be observed frequently by examination of the flow at the outlet and through manholes, observation wells, etc., and if any portion becomes inactive it should be looked after at once, for it should be remembered that the damaging alkali salts have not been removed entirely by drainage, and that a subsequent rise of the ground-water table certainly will be followed by a new accumulation of these harmful substances.

NECESSITY AND ADVANTAGES OF COOPERATION.

Frequently it is not feasible for one individual to drain alone, and it is almost never economical to do so. The unit cost of drainage decreases as the size of the tract increases. This is due partly to the fact that a system installed on a small tract receives water from

without the boundaries of the tract and accomplishes more or less complete drainage over a considerable area. Furthermore, the unit cost of all materials and operations is less on the larger projects, and the required capacity of drains becomes relatively smaller as the unit becomes larger while the cost per unit of water carried is much less in the case of large tile than in the small. Economy demands that tracts as large as possible be handled as units, and where the land is owned by a number of persons it is necessary that some sort of cooperation be effected. Cooperation by mutual agreement usually is difficult and sometimes impossible to secure, owing to an unprogressive spirit among some of the landowners. Cooperation under an official organization is much more satisfactory and effective, and the legislatures of practically all the Western States have provided laws under which cooperative work may be done.

In general, these laws provide for the formation of drainage districts and for their government, prescribe their powers and privileges, and outline the duties of their officers. The direction of the business of a drainage district is in the hands of a board of drainage supervisors who are appointed by the county commissioners or the district court, depending upon which is the recognized authority in the matter of formation of drainage districts. Drainage districts may exercise the right of eminent domain and bonds may be issued to pay for the construction work. The bonds are retired by assessments collected in the same way and as a part of the regular taxes against the property, so that the cost of reclamation is borne by the returns from the land and is not a direct burden on the landowners. The construction work should be done under the direction of a drainage engineer appointed by the board of supervisors.

The usual procedure is to present a petition to the court or board stating that the lands are in need of drainage and that the benefits of reclamation will exceed the sum of the damages caused and the cost of the work. Hearings are held after due notice has been given, and the district is organized as a legal institution. In most States the organization of such districts is effected so easily and the operation under the law is so simple that it is advisable to make use of this method in carrying out the work.

CONCLUSIONS.

The drainage of wet and alkaline lands in the irrigated section is entirely feasible and may be accomplished economically if properly done. Such drainage must be the basis for the reclamation of these lands. Tile drainage is recommended for farm practice. Thorough studies of subsurface conditions must be made before successful systems can be designed. The present demand for the products of the farm make it imperative that these lands be reclaimed.

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